POTENTIAL SHALE OIL RECOVERY METHODS IN THE GREEN RIVER FORMATION AND ASSOCIATED ENVIRONMENTAL PROBLEMS

Senior Thesis

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for the degree of Bachelor of Science in Geology

by

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DEDICATION PAGE

Dedicated to:

Damien, my brother, whose recent and sudden death at the age of 20 cut short his buoyant aspirations and youthful dreams for a successful future in marketing and spanish.

My parents, who insist a science degree today insures a job for tomorrow.

Dave Patton, whose friendship means a great deal to me.

ACKNOWLEDGMENTS

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ABSTRACT

The United States faces a serious energy crisis and needs to develop new long term domestic sources of energy. One important and untapped source is oil shale. Tapping this resource is an alternative way to lessen U.S. dependence on foreign oil and become more self sufficient. The oil shale, an oil bearing rock that fills the uplands of Colorado, Utah, and Wyoming, contains an estimated 1.8 trillion barrels of oil, or three times the known reserves of the Middle East. At the current rate of consumption, that amount of shale would supply U.S. needs for more than a century.

Although oil shale companies know where to find their fuel, they differ on the best way to get it out. The original idea of the oil shale developers relied on so-called surface retorting technology. The shale was strip mined, crushed, and then heated to very high temperatures in huge chambers. The temperature was kept at about 900°F, and this process was called "retorting." This high temperature breaks down the rock's solid hydrocarbon component, kerogen, into oil. The raw shale oil is then cleaned for use as refinery feedstock.

To obtain increased yields, cut mining and processing equipment costs, reduce spent shale surface disposal, and limit pollutants emitted in the air, the competitive technology developed the "modified in situ" method below ground. This method extracts shale oil from rock by heating it in underground chambers called retorts. Explosives are detonated in the retorts to reduce the shale to rubble. The shale heap is then lit, and the fire is drawn down through the chamber. The intense heat of

the blaze frees the oil from the rocks; then it settles to the bottom and is collected for refining into the desired hydrocarbon products.

The greatest unknown about shale-oil production is its impact on the environment. Conservationists claim that one to five barrels of water are required for each barrel of oil extracted from shale. Critics also complain about the release of salts and arsenic into the region's groundwater from surface runoff of the piles of leftover shale rubble. The air could become filled with dust from all the rock that is being unearthed and processed. The final, but poignant protest, concerns the scenic destruction of the Rocky Mountain Valleys. Piles of spent shale residue could clog the valleys if mass stabilization is not accomplished by contouring and planting the dump with local grass and wildflowers. This is a big problem considering the fact that a 400,000 bbl-a-day industry requires 500,000 tons of shale to be mined and retorted. This paper will attempt to address and clarify these problems.

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Introduction

Renewed interest in alternate sources of hydrocarbons has developed due to the increased demand for fuels, chemical feedstocks, and the realization of the finite nature of petroleum products. As the nation's supplies of conventional fuels dwindle and become more costly, development of our vast oil shale resources can help to stabilize the future energy situation. Prerefining the product shale oil from the retorts yields a premium feedstock containing virtually no sulfur. Our domestic oil shale resources are capable of providing oil for approximately 200 years. Although oil shale has been processed to produce hydrocarbon products for more than 100 years, engineering development problems must be solved before this resource can be competitive in the marketplace.

I. BACKGROUND ON OIL SHALE

What is oil shale

Oil shale is neither shale nor oil. The rock, marlstone, is a very fine grained variety of limestone that contains organic matter or a solid fossil fuel called kerogen. When it is processed properly, it can yield at least 10 gallons of oil per ton. However, most commercial interest is centered upon shales that yield from 25 to 65 gallons of oil per ton.

The solid organic portion of oil shale, which is combustible, is composed of carbon, hydrogen, oxygen, and some small amounts of nitrogen and sulfur. Bitumen, incombustible asphalt-like material mixed with solid organic material, can also be present in substantial amounts. The rest of the rock is made up of incombustible minerals such as calcite, dolomite, clay, quartz, and feldspar.

The color of oil shale is dark black, brown, or grey, but waxy organic materials can color some layers yellow, green, or red. When a thin slice of oil shale is viewed under a microscope, dark shapeless masses of organic matter surround the other mineral grains. A large percentage of these particles are fossil remains of spores, pollen or filaments of algae.

How oil shale was formed

Oil shale formed where plant or animal life was abundant and was deposited as layers of organic ooze and mud on the bottoms of ancient lakes, ponds, lagoons, and shallow seas. As organisms died and sank to the bottom, their remains became partially preserved. The best environment for thick accumulation was where the water was stagnant and lacked sufficient oxygen for complete decay of organic matter. As the rich organic layers of mud were gradually buried by younger sediments, the weight of the overlying material slowly turned the mud into hard shale. These lake bed deposits were never subjected to temperatures above 300°F and extreme pressures during time. Thus, they did not form the more readily usable natural gas and crude oil.

Deposits in the Green River Formation

The Rocky Mountain region contains the most extensive high-grade deposits known in the United States. The most important area is the Green River Formation which underlies a 17,000-square-mile area at the intersection of Colorado, Utah, and Wyoming (Figure 1, p. 4). This is about 100 miles east of Salt Lake City. These sedimentary deposits accumulated in the bottoms of two vast shallow lakes that existed during the Eocene Epoch of the Tertiary Period, roughly 50 million years ago. The Green River Formation is named after the Green River in Wyoming. Many of these layers of oil shale are visible in cliffs and ledges along present-day stream channels. The U.S. Geological Survey has determined that the richest oil shale deposits are buried near the central parts of the ancient lake basins beneath younger sedimentary rock. This area has at least 25 feet of continuous beds yielding greater than 25 gallons of oil per ton. It has been estimated that these beds contain about 660 billion barrels of oil. This figure is comparable to the world's proven reserves of crude petroleum.[2]

The 1,600 square mile Piceance Creek Basin of northwestern Colorado

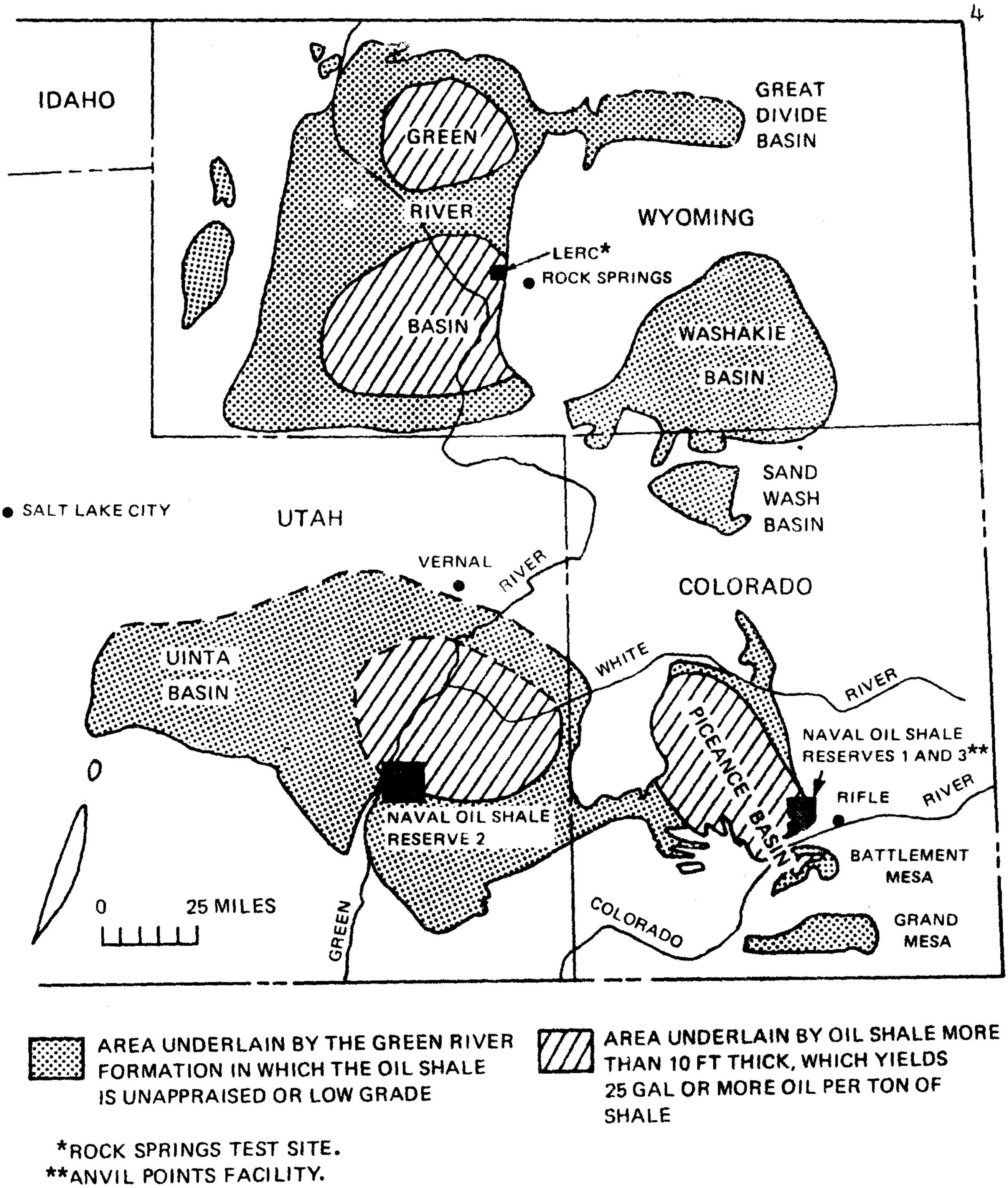

FIGURE 1. OIL SHALE DEPOSITS IN THE GREEN RIVER FORMATION OF COLORADO, UTAH, AND WYOMING[1]

contains the largest deposits of high-grade oil shale or about 75 % of the proven reserves. The southern part of the basin is composed of the rich Mahogany Zone which ranges from 50 to 100 feet in thickness. In the north-central part of the basin, approximately 1,000 feet of rich oil shale lies buried under 500 to 1,600 feet of sandstone and lean or barren shale. It has been estimated that the equivalent of 1.3 trillion barrels of oil exist in the Piceance Basin alone, including both high and low-grade shale. The south and east margins of the Uinta Basin in Utah also contain thick layers of oil shale. Generally, the layers increase in thickness and improve in quality below the surface in the eastern half of the basin. The Green River Basin in Wyoming is the other source of thick layers of rich oil shale which are buried deep in the earth.

At present, commercial interest lies only in the highest grade and more accessible oil shales of the Green River Formation. These potential resources are more than double the proven petroleum reserves in the country. At costs competitive with petroleum of comparable quality, and using current technology, the proven reserves could yield roughly 80 billion barrels of recoverable shale oil.[3]

Why oil shale originally was not competitive

Development of our shale oil resources has not taken place earlier primarily because conventional petroleum has always been cheaper than the projected price of shale oil. As a result, shale-oil has had difficulty in replacing any significant quantity of imported energy. Depending on the technology employed, the cost of oil shale at 1980 prices is $ 15 to $ 30 per barrel. But large cost overruns in construction, shale oil recovery procedures, and other unexpected events can push the price higher. Many industry experts say that \$ 25 a barrel or more will be needed for shale oil to provide a 15 % return on investment. At present, that price is too high to compete with OPEC oil unless a proposed tax credit is passed.[4] An economic boost that the U.S. Department of Energy can give the shale oil developers proposes to pay the developers the difference between the higher cost of their product and the weighted average cost of oil in the U.S., taking into account both domestic and foreign supplies.[5] This could help stimulate investment and production within the industry.

Another big problem confronting shale oil development is the large number of plants and the extensive scale of the mining required to produce it in quantity. Twenty commercial plants producing 50,000 barrels a day would be required to supply just five percent of our present energy needs for liquid fuel. A problem of equal importance are the environmentalists who are concerned because so much industrial disturbance could upset the fragile, semiarid Colorado River basin where the richest shale deposits are concentrated. Environmental objections could result in a production ceiling of one to two million barrels a day being placed on the size of the industry.

II. HOW TO EXTRACT OIL FROM SHALE

Thermal decomposition of kerogen

Shale oil is not a crude oil, but a solid waxy hydrocarbon called kerogen. Shale oil is obtained by the destructive pyrolysis of crushed ore and the subsequent thermal decomposition of kerogen at an atmospheric temperature of 900°F. The high temperature retorting process turns the organics into oil vapor. Shale oil is composed of the hydrocarbon condensation products of the vapor. In this state, shale oil can be used only for boiler fuel. Then it must be treated with hydrogen to remove nitrogen and arsenic which are poisonous to refinery catalysts. After this procedure, it can be refined into more valuable products. The shale oil characteristics are determined by the shale source and by the retorting method which is used. When shale oil is compared to petroleum, it is shown to be a heavy, viscous oil with a high pourpoint and a high nitrogen and sulfur content. Results are shown in TABLE 1.

Table I. Comparative characteristics of petroleum and shale oil.[6,7]

Source	Gravity °API	Sulfur Wt %	Nitrogen Wt %	Pour Point ° F	Analysis of Distillates Boiling Below 600° F (Vol. %)		
					Saturates	Olefins	Aromatics
Midcontinent Petroleum	39.0	0.14	0	5	90	0	10
Shale oil from Colorado shale by five retort methods	16.0-25.7	0.6-0.8	1.6-2.2	60-90	26-36	36-46	28-32

Once the shale oil is upgraded, it is a premium refinery feedstock that can be superior to the best Saudi Arabian light crude. It also yields large quantities of quality diesel and aircraft fuel.

Means of transferring heat to oil shale

Oil shale retorts, or heat exchangers, transfer heat from a heating medium to the shale. Based on the method of heat application, they are divided into four general classes:

Class	Method of heat application to the shale	Examples
I	Heat is transferred to the shale through a wall.	Pumpherston
II	Combustion by burning product gases and residual carbon in the retorted shale within the retort.	Union Oil Company
III	Previously heated gases or liquids are passed through the shale bed.	Bureau of Mines gas-flow
IV	Introduction of hot solids into the retorting bed.	Tosco (Matzick *et al.*,1966)

Criteria for effective recovery of shale oil

If the retorting process of the Colorado oil shale is to be economically feasible, the following requirements are desirable. It should:

1. Be continuous.
2. Have a high feed rate per cross-sectional area.
3. Have high oil recovery efficiency.
4. Require a low capital investment, and possess a high operating time factor with low operating costs.
5. Supply all heat and energy requirements without burning any product oil.
6. Have the capacity to be enlarged into high-tonage retorts.
7. Require little or no water due to the aridity of the Green River oil shale region.
8. Be able to process efficiently a wide range of oil shale particle sizes to minimize crushing and screening.
9. Be easily operable.[8]

III. POTENTIAL SHALE OIL SURFACE RETORTING PROCESSES

The above ground retorting method involves mining oil shale, crushing and retorting the material in surface operations, and disposing of spent shale residue. Waste water is used for quenching, and the net products are shale oil, mine overburden, and spent shale ash.

Gas-combustion retorting process

The gas-combustion process is the one process that meets most of the desirable characteristics previously mentioned. It employs the use of a continuous flow of shale by gravity, direct gas-to-solid heat exchange, and heat supply by internal combustion (Figures 2 and 3, p. 10).

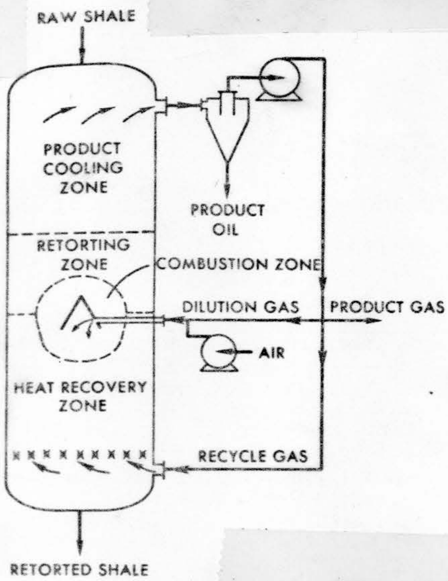

Figure 2. Gas-combustion process (Carpenter et al., 1978)

The retort is a vertical, refractory-lined shaft which is equipped with shale-and-gas-handling devices. Although there is no physical separation

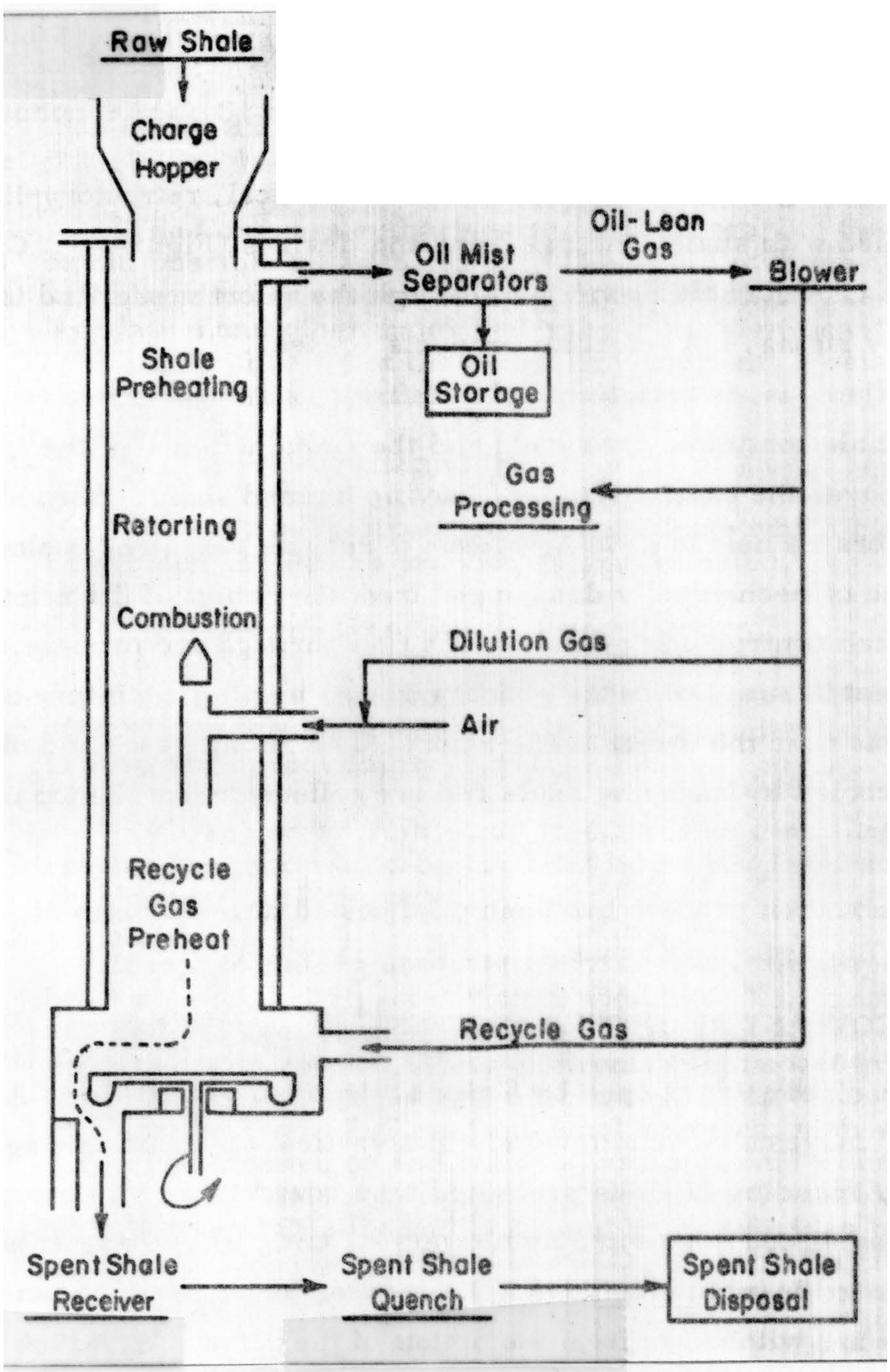

Figure 3. Bureau of Mines Gas-Combustion Retorting Process (Matzick et al., 1966)

or definite dividing line, it is convenient to divide the retort into four functional zones: The Product Cooling Zone, Retorting Zone, Combustion Zone, and Heat Recovery Zone.

First, the crushed and sized raw shale moves downward through the retort vessel and enters the product cooling zone. Here the rising gases from the retorting zone heat the solid particles to approximately retorting temperature. The organic matter then moves to the retorting zone where heat decomposes it in order to liberate oil vapor and gas. Some retorted shale particles are converted to carbonaceous residue after this reaction. Next, the retorted shale enters the combustion zone. Heat for this process is obtained by burning the organic residue on the shale and some of the product gas which is returned to the system. Now the shale moves to the heat recovery zone and transfers its heat to the rising stream of recycle gas. Finally, the retort mechanically discharges the cooled spent shale at a controlled rate which governs the retort throughput (Matzick *et al.*, 1966).

The recycle gas, which rises through the spent shale in the heat recovery zone, is injected from the bottom of the vessel. This zone is actually a countercurrent gas-to-solids heat exchanger. Air, diluted with part of the circulating retort gas, is injected near the center of the retort from an air distribution device. When the mixture encounters the hot spent shale, it is heated quickly because the reaction of oxygen with combustibles produces a hot flue gas. Thermal decomposition of the kerogen in the shale occurs when the hot flue and recycle gases rise and contact the descending raw shale in the retorting zone. The liberated gases and oil vapors, along with the upward rising gas stream, are cooled by the entering raw shale in the product cooling zone. At this point the oil condenses as a fine mist or fog and is carried out of the top of the retort. The retorting and cooling zones are both countercurrent gas-to-solids heat exchangers. However, retorting reactions and oil condensation complicate their functioning (Matzick et al., 1966).

In order to recover the shale oil, the overhead stream from the retort must first pass through the oil-mist separators. The oil-lean gas now enters a blower, and upon leaving, it has a higher temperature and is divided into three streams. One, dilution gas, mixes with air and is injected into the center of the retort. The second part, recycle gas, enters the bottom of the retort. The remainder, net product gas, is vented from the system (Matzick et al., 1966). A typical material balance and pertinent temperatures are shown in TABLE 2.

Table II. Typical Gas-Combustion Retort Material Quantities and Temperatures (Matzick et al., 1966)

	Weight, pounds	Volume, std cu ft	Temperature, °F
Material in:			
Shale	2,000	--	60
Recycle gas	1,134	14,850	129
Dilution gas	148	1,940	129
Air	294	3,840	91
Material out:			
Retorted shale	1,611	--	166
Product oil	196	--	129
Total retort gas	1,769	23,170	129

Temperature and location of shale oil mist formation

Shale oil mist forms just above the retorting zone. This zone is where the rate of shale decomposition becomes appreciable, and where a shale temperature of 700°F exists (Figure 4).

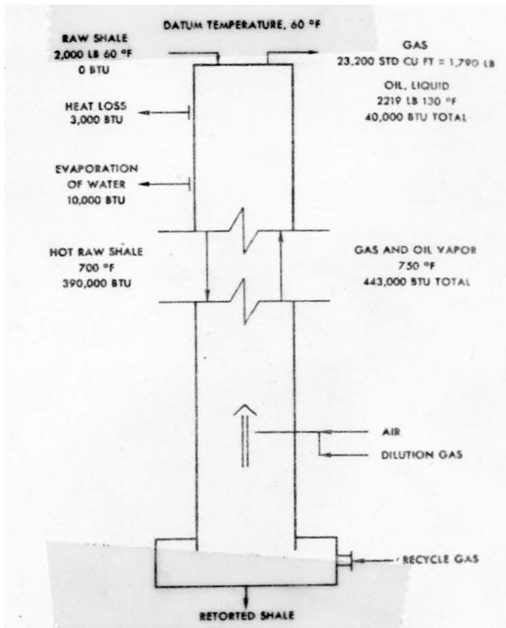

Figure 4. Mist formation section of the gas-combustion retort (Matzick et al., 1966)

As the downward moving oil shale is heated almost to retorting temperature, the rising gases and vapors are cooled to the temperature of the retort outlet. If the operating conditions of the retort are satisfactory, then oil will condense in the upper section as a fine mist which is easily carried out with the gas.

If the oil is to leave the retort as mist in the offgas stream, then the droplets must form in the spaces between the shale particles. The droplets must also be small enough so that inertial separation does not occur when the gases carry them upward through several feet of shale bed (Matzick et al., 1966). Since the formation of a stable mist is an essential part of the gas-combustion process, then the effective operation of the process requires understanding of the factors controlling the mist formation. Refluxing is one of these factors.

The refluxing problem and its effects

It is impossible to prevent some condensation and deposition of oil on all the particles of shale entering the retorting zone. If the amount of oil on the shale is great enough to flow down through the bed of shale, then a refluxing problem will occur.

Part of the oil on the pieces of shale will redistill as the bed is subjected to increasing temperatures while moving down the retort. The heavier fractions are thermally cracked before reaching their boiling point. This cracking forms lighter oil, gas, and coke. Most of the lighter oil is recoverable. However, a loss of yield in the primary product occurs with the gas and coke formation. Thus, substantial losses and altered products can occur if refluxing is not controlled (Matzick et al., 1966).

Refluxing can also cause operational difficulties. Interference with the flow of shale or its complete stoppage can occur when the coke that has formed bonds the shale particles into large agglomerates. Refluxing also can alter dramatically the temperature within the retort.

Under refluxing conditions, a considerable oil stream volume moves downward through the shale bed. Due to the thermal effects of revaporization and secondary cracking, the downward flow of oil will alter the heat distribution in the mist formation section. The oil film also tends to reduce the heat transfer coefficient between the hot gas and shale. Thus, as compared to a nonrefluxing operation, refluxing conditions tend to increase the temperature near the top of the bed because condensation will cause heat release. The temperature of the lower bed will decrease because of the heat load imposed by vaporization. Other thermal effects attributed to refluxing include changes in:

1. The void space pattern of the shale bed.
2. Carbonate decomposition.
3. Offgas temperature (Matzick et al., 1966).

Clinker formation

Another problem associated with a moving bed retort is the flow of solids through a retort vessel. The resistance to solid flow of air/gas distributors, segregation of various particle sizes, wall effects, and other operational problems produce localized heating which can cause clinker formation. Clinkers impede the flow of solids, and through bridging, can completely stop the flow through the retort vessel. Bridged material must be mechanically removed before the retorting process can continue.[9,10]

Advantageous features of the process

High thermal efficiency is a distinct advantage of the gas-combustion process. Since a large part of the sensible heat of the retorted shale is recovered, it is only necessary to add about 400,000 Btu per ton of shale. The low heat requirement is made possible because of the combustion of both the easily burned portion of the carbonaceous residue on the shale particles and part of the gas. The capacity of the gas-combustion process is not limited by combustion rates but other factors. These factors comprise the tendency for fine shale particles to become entrained in the gas stream as throughput is increased, and the occasional pressure drop that occurs through the bed (Matzick *et al.*, 1966).

The presence of mineral carbonates helps to alleviate the problem of severe shale fusion which occurs at high temperatures. Under normal gas-combustion retorting conditions, endothermic carbonate decompostion reactions absorb 160,000 Btu per ton of shale. The carbonate decomposition limits the maximum shale temperature to about 1,600°F. This is several hundred degrees below the fusion point of the present inorganic matter (Matzick *et al.*, 1966).

Another advantage of the gas-combustion retort lies in its mechanical simplicity. Both gas and shale distribution devices are stationary, and the retort vessel itself is designed simply. Due to the low temperatures and mechanical forces involved, raw and spent shale present few handling problems. The most critical part of the system is the air distributor at the combustion zone. Here special attention is given to its design, arrangement, material selection, and operation technique.

The Paraho process

The Paraho process resembles the gas-combustion process, but it incorporates some major refinements. The major improvements of the Paraho process are better process control, including solid and fluid flow, and the ability of the process to be operated in an externally heated mode. The more precise control minimizes operational problems such as bridging and loss of liquid product by refluxing on the cold shale. In regard to the externally heated mode, the energy used for the process is provided by burning part of the recycle gas stream in a external heater. Under the influence of the externally heated mode, the quality of the recycle gas can be improved, but the liquid oil recoveries remain unchanged (Carpenter et al., 1978).

The Union Oil Company process

The Union Oil Company has a retorting process which utilizes a rock pump in their retort. Union's process feeds a continuous stream of crushed shale into the bottom of a tall, cylindrical retort, and then forces it up and out the top. The rock pump acts as a piston-type feeder and forces the shale particles into an inverted, cone-shaped vessel. This vessel has an open end at the top, and it is in contact with the atmosphere. Once the shale is retorted in the lower regions of the vessel, the remaining spent shale solids will overflow from the retort vessel's top rim (Figure 5, p. 18).

Other engineers claim that it is easier to let gravity do the work of sustaining the flow of shale through the retort by letting the flow in at the top and out the bottom. However, Union officials say that despite the rock pump having to work to overcome gravity, it alleviates the

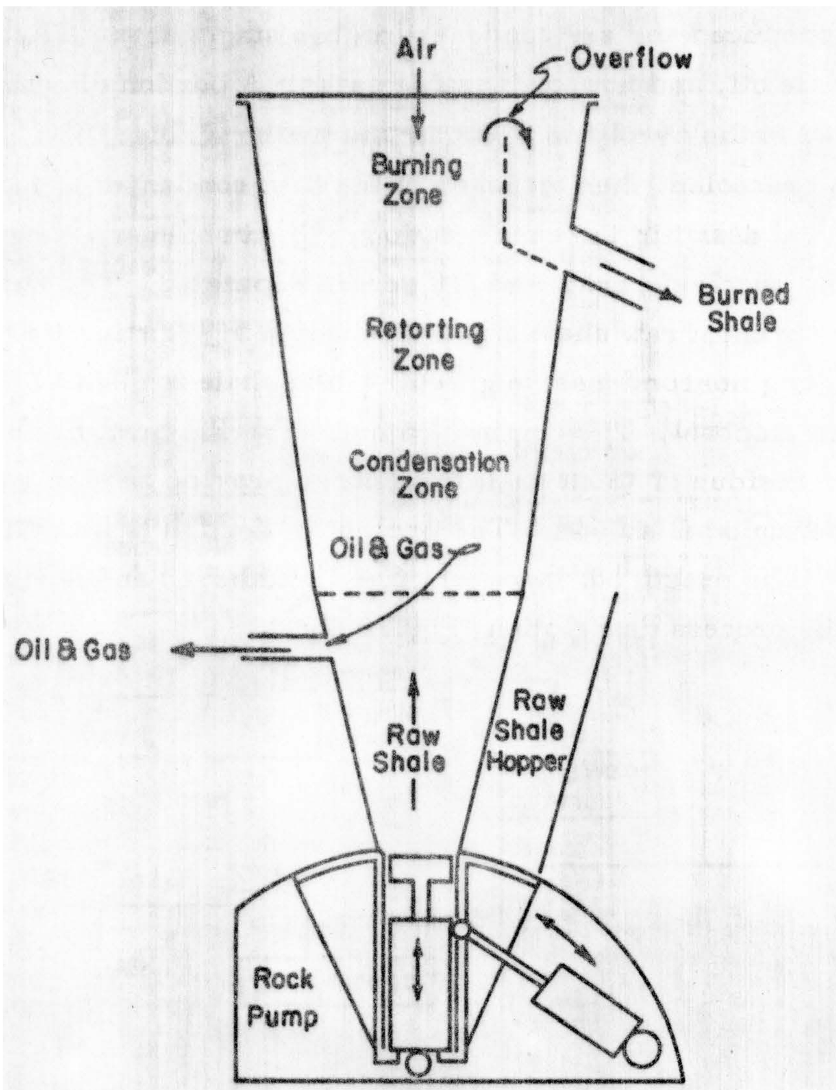

Figure 5. Union Oil Retorting Process[11]

problems of bridging and secondary cracking. The bridging problem is solved because the rock pump breaks up any bridging in the material. This prevents the pieces of shale from sticking together in the intense heat. Thus, the spent shale is forced from the vessel. Air can also enter the moving bed at the top of the vessel and flow downward, countercurrent, to the flow of solids. Secondary cracking is much less of a problem and refluxing is less likely to occur due to the influence of gravity.

In 1974, Union Oil Co. made an improvement to the old internally heated process by covering the top of the retort to prevent air from being admitted. This is called the SGR process, and it stands for steam-gas-recycle. The spent shale is transferred to a seperate vessel where oxygen and steam react with the residual carbon left on the spent shale. The hot synthetic gas that is produced in this upper vessel is then injected into the shale at the bottom of the retort. This gas provides all necessary heat for retorting the incoming shale. This is in contrast to the Union "B" process where heated recycle gas is used to provide the necessary heat for retorting oil shale (Carpenter et al., 1978).

The Tosco II retorting process

The Tosco II retorting process is another externally heated process which supposedly recovers virtually all the shale oil (Figure 6, p. 20). This process uses a rotating pyrolysis drum as the retorting vessel, and marble-sized ceramic balls as a heat transfer medium. The balls are super-heated in an external vessel by burning residual carbon on spent shale particles. The raw shale is then crushed to a fine consistency, pre-heated and cooked by mixing it in a rotating retort with preheated ceramic

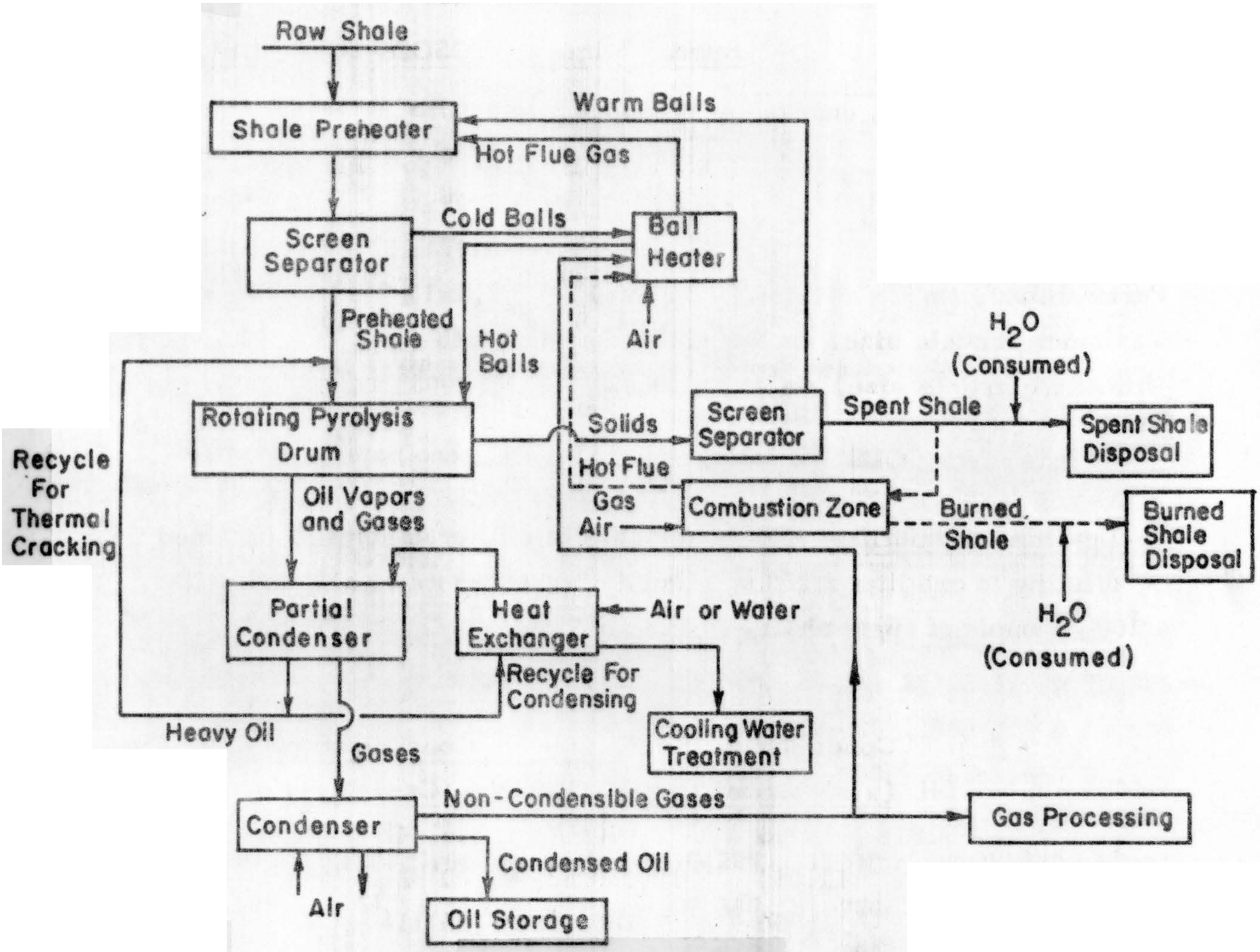

Figure 6. Tosco Retorting Process[12,13,14]
(Alternate Pathway Dashed)

balls. The ceramic balls supposedly keep the temperature evenly distributed. Direct contact between the two, at retorting temperatures, produces gas and oil vapors. The gases that are produced cannot be diluted with nitrogen since combustion air is not admitted into the closed retorting vessel. Thus, the gases have a high heating value. These products are then condensed in two stages and yield heavy oil, crude shale oil, and noncondensable gases. A portion of heavy oil is recirculated into the pyrolysis drum for thermal cracking. The remainder is precooled, and atomized in the first condenser to remove dust aerosol and to assist in the condensation. Then the warm ceramic balls and spent shale are removed from the pyrolysis drum and separated from each other with the use of a screen. In the next step the warm balls are used to preheat raw shale and reheated to retorting temperatures by burning condensable gases. Before the spent shale is disposed of, it is quenched with water (Culbertson, 1962). The shale oil product differs from that of the gas-combustion process since it has a slightly higher API gravity and a lower pourpoint. The recovery of the hydrocarbon values from the raw shale is also high (Carpenter et al., 1978). This method does have some critics. Competitors say that the spent shale is so fine that it creates more dust than the coarser shales produced by most of the other methods, and that the resulting extraction of the oil is not efficient.

IV. UNDERGROUND RETORTING

Oxy's "modified in situ" method

To obtain increased yields, cut mining and processing equipment costs, and eliminate costly surface installations that may also pollute the environment, Occidental Petroleum Corporation has developed an underground retorting method called "modified in situ" (Figures 7 and 8, p. 23). This method extracts shale oil from rock by heating it in place in underground chambers called retorts. The term "modified in situ retorting" has two definitions. One refers to an "in situ retort" in which a part of the material has been removed to allow for expansion during fracturing of the oil shale bed. It is called "modified in situ" because the shale mined at the beginning still has to be disposed or retorted above ground. The other definition applies to underground retorts prepared by solution mining of soluble salts either by natural or artificial means. "True in situ processes" involve little or no removal of material prior to fracturing.[15]

Chambers, the size of a football field and 250 to 300 ft. high, are constructed by drilling parallel tunnels from a vertical mineshaft into the rock at two different depths. To allow for proper expansion of oil shale rubble during the formation of the retort, underground mining is used to remove at least 20 % of the retort's volume. The next step involves reducing the subsurface shale to a fractured rubble pile. One approach places conventional or nuclear explosives beneath or within the formation and a subsequent detonation. The other approach, which is designed to increase the permeability of the formation, combines conventional explosives with hydraulic fracturing (Pfeffer, 1974). Experience has shown that more oil will be recovered from rubble of even or uniform size as the flame front passes through the retort (Nulty, 1979). Approximately 500,000 pounds of explosives are planted at the top and bottom of the remaining rock and detonated at millisecond intervals. The shale is

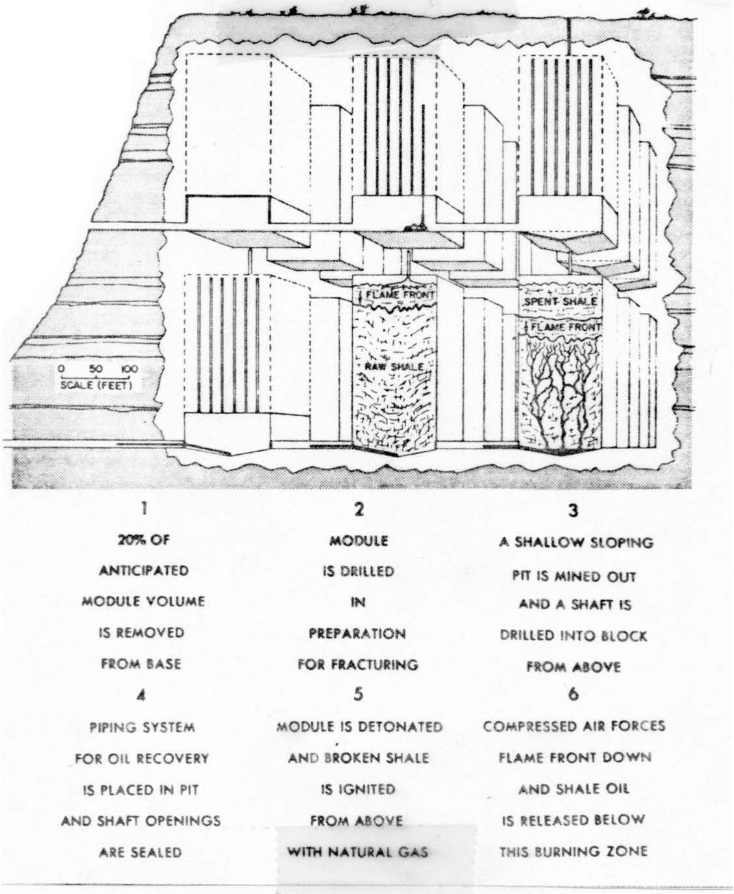

Figure 7. Simplified sequence for modified "in situ" oil shale retorting[16]

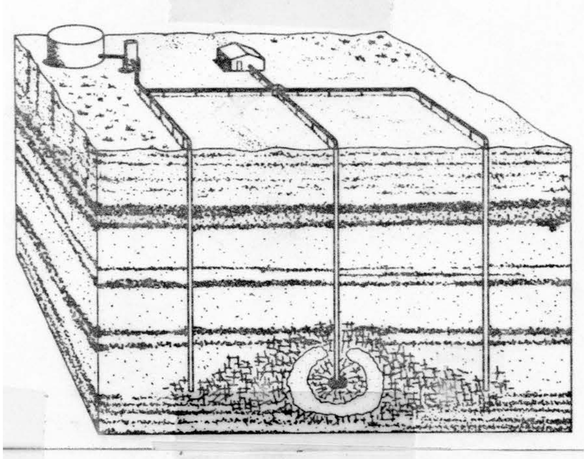

Figure 8. True "in situ" retorting process (McCarthy and Cha, 1976)

reducedto rubble which expands into the voids.

This creates a kind of underground "furnace." A network of wells is installed after the explosion, and an induced fire front is used to retort the fractured shale. Shale oil, an external fuel source, is ignited and used to heat the top layer of shale. In order for the retorting to begin, the temperature must reach 900°F. Once the temperature is reached, the carbon of the retorted shale serves to fuel the process. At a rate of one to two feet per day, the combustion in the "furnace" moves slowly downward (5). Combustion is sustained by injecting air. The oil shale is retorted when it comes in contact with the heated combustion products, and it is forced to flow in their same direction. The heated shale forces the oil out of the rock, and under the influence of gravity, it flows to the bottom. It is collected from this bottom position and a water-shale oil mixture is pumped to the surface for separation. Shale oil and a waste water that requires treatment are the net products (Pfeffer, 1974).

<u>Operational problems of "in situ mining"</u>

Some retorts have failed because of an inability to break the shale into symmetrical pieces to allow uniform heating. Another problem has been the fact that the modified "in situ method" has been tested on medium-grade shale containing 15 gallons of oil per ton of rock. Since most commercial development is planned on the assumption that oil rich shale will yield up to 40 gallons of oil per ton of rock, one wonders about the viscosity of the oil affecting the process. In such huge concentrations of oil, the kerogen will not break down. Instead it will turn into a plastic mess that seals off all oil flow. Thus, the process will have some problems with a rich oil shale deposit, and low oil recovery could result (5). The Bureau of Mines has also experienced a problem with full-scale "in situ operation" in Rock Springs, Wyoming. When they tried to induce a fire front to retort the fragmented shale, there was an inability to control the direction of the fire front.[17]

One of the other important factors that determines the success of the "in situ process" concerns sufficient permeability of the retort to allow the flow of retorting fluids into and out of the retort. With adequate permeability, heat can be distributed evenly throughout the shale bed. It is essential that the permeability be maintained throughout the life of the retort, and it must be limited so that the flow of fluids can be contained within the desired volume (Carpenter et al., 1978).

Advantages of the "in situ retorting process"

There are several potential advantages of retorting oil shale underground by Oxy's method as compared to aboveground processing. The "in situ method" is more economical than ordinary mining techniques when shale deposits are deeply buried, too lean, or the strata is too thin. It also has some advantages in removing rich, thick deposits of oil shale. The "in situ process" is less capital intensive since aboveground installation is less complicated and less expensive. There are fewer problems associated with the disposal of waste products since the spent material remains underground. Fewer air pollutants are released in the air than its aboveground counterpart. The last advantage deals with efficiency of oil recovery. Conventional mining and processing would produce 300 million bbl. of oil from a tract, whereas, the "in situ method" would squeeze 1.2

billion bbl. from the same ground. That is four times the amount recovered than from the surface method (5).

V. CRITERIA USED TO PICK MOST EFFICIENT PROCESS

Determinants for the best extraction procedure

The extraction procedure depends upon the depth of overburden and the thickness and structural integrity of the oil shale beds. For example, high grade shale beds up to 2000 feet thick, but yielding at least 1,000 feet of possible overburden, exist in the center of the Piceance Creek Basin of Colorado. Since current surface retorting technology is limited to about 400 feet of overburden, an underground procedure would be necessary. Besides the bed thickness, the degree of fracturing would also determine the method employed.

Modular development

Modular development provides a deliberate but safe start that could be accelerated later. It minimizes the risks of producing too many flawed commercial plants during periods of high inflation and environmental degradation. Technical feasibility has been shown, since the gas-combustion process, the Paraho process, the Union Oil process, and the Tosco II process have all operated successfully while handling 1,000 tons of broken shale per day. However, if these processes are to make significant contributions to today's energy demands, they must be scaled up by a factor of 10 to 20. This would result in a commercial-sized module, which could demonstrate realistic operability and provide reliable economic data. If five or six of these plants could be tested by 1985, with successful results, more modules could be added to bring total production up to 500,000 bbl. -a-day by 1990 (Nulty,1979).

All these retorting methods have produced similar shale oils. Based mostly upon the information derived from gas-combustion crude oils, it has been found that these oils are made up of about 40 percent hydrocarbons and 60 percent organic compounds containing oxygen, nitrogen, and sulfur. The oils are deficient in gasoline boiling range material and approximately half of this material can be recovered during distillation. As of now, the major use of the crude oil is for burner fuel. However, the current energy needs require refined fuels for transportation, gasoline, jet fuels, and diesel fuels. Although shale oil cannot totally solve our energy problem, it is one of the few technologies that has great potential for relief from OPEC prices. Thus, it is essential that research on upgrading, refining, and developing our retorts be developed to obtain the country's desired hydrocarbon products.

VI. ENVIRONMENTAL PROBLEMS

Shale disposal

Regardless of which technology is used, oil shale development faces unresolved environmental problems. Spent shale disposal is one of the major concerns. Significant quantities of retorted oil shale surface residue can result for two reasons. One, because the volume of spent shale increases after retorting. Two, the lack of available space for spent shale disposal.

When raw shale is crushed before retorting, its volume per unit mass is doubled. Once it is retorted, approximately 40 % of the volume is lost (Pfeffer, 1974). Spent shale, as compared to raw shale which is in place, occupies a 20 % greater volume. Until adequate void space is available, spent shale disposal at mine sites cannot be permitted. The amount of waste disposal that will occur depends on many variables which include the retorting method and temperature to which the shale is subjected, the grade and crushing requirements of the raw shale, the amount of disposed waste during mining operations, the by-product usage in the area concerned, and the recoverability of saline minerals. If one uses the 20 % volume figure from above, a 50,000 bbl./day plant could produce an excess of 260,000 ft^3/day of spent shale that would not be returned to the mine. This is assuming raw shale assays 25 gal./ton and occupies 15.5 ft^3/ton in place. The excess amount would be able to cover the 65 square mile area of Washington D.C. to a depth of 1/2 inch per year. This figure increases to a foot per year if one uses a one million bbl/day plant (Pfeffer,1974).

Rainfall and snowfall impact on shale dumps

Since long reaches of canyons will probably be filled with shale waste up to 600 ft. depths, it is necessary to determine the impact of rainfall and snowfall on the stability of the material. Colorado State University conducted pilot investigations, using small plots with maximum depth of two feet, on three retorting operations: the Union Oil Company, Tosco, and the Bureau of Mines. Since the Tosco process was the closest to being commercially developed, it received the most attention. Maximum raw shale size, after crushing and retorting operations, was 0.5 inch. The residual solid waste was a finely-divided black residue (Pfeffer, 1974). At the end of the rainfall and snowfall investigations, some interesting contrasts were discovered. The surface runoff from rain contained more total dissolved solids than the solid concentration in the runoff from melting snow. This was due to the low rate of runoff from melting snow. After several hours of rainfall, the wet shale surface still remained sufficiently firm to support walking and little or no footprints were registered. However, the important findings related to percolation. Water penetration and subsequent saturation to maximum depth into the shale bed occurred with long periods of contact with melting snow. The saturation caused the surface to no longer support walking, and the effects of compaction were reduced. With water saturation conditions existing, mass movement by slumping or sliding is very likely. Thus, in order to stabilize a disposal site containing shale of the nature tested, the moisture content of the shale must be controlled (Pfeffer, 1974).

Stabilization of spent shale piles

The approach to achieving stability of the spent shale dumps involves the following preventative measures:

1. Drainage of water away from the top surface can be accomplished by contouring the surface in benches to prevent erosion during heavy rainfall.

2. Diversion of upstream surface water and side wall canyon runoff around the dumpsite can prevent soil saturation and lower the water table in shallow aquifers beneath the pile.

3. Once the shale surface has been compacted, the exposed surfaces should be sealed to prevent water penetration. A bentonite clay mixed with the surface material would be an effecitve sealing agent. This impermeable barrier should then be covered with a layer of sand or crushed rock. Native overburden or conditioned soil is then placed over the sand layer.[17] Stabilization of the overburden is accomplished by revegetating the surface with native plant cover, such as juniper or sagebrush, or by covering the surface with "unattractive" plants which have grown by natural succession on abandoned mine sites in the area (Pfeffer, 1974).

4. If the "unattractive" plants cannot prevent foraging animals from disturbing the newly vegetated area, then the dump site should be fenced off. The fence would be maintained until the revegetated site is able to support the grazing of native animals.

5. Compression of the soil material in the canyon floor by the overburden could result in the rise of alluvial ground water tables to the base of the pile and subsequent saturation of the pile's lower layers. Drainage channels could be emplaced in the subsurface in order to lower the water table and prevent possible water discharge into the shale bed.

Leached products from spent shale

A concern of many environmentalists is what would happen to the quality of any rainwater or effluents that drain off the plant sites. Rainwater has the potential to leach out salts, traces of fluoride, boron, and molybdenum which are contained in the spent shale. These could be carried by streams to the already too saline Colorado River. However, proper waste pile construction, like that mentioned above, can prevent salt leaching in a fresh water resource.

Radioactive contamination of groundwater

The use of nuclear detonation devices has been suggested for "in situ" formation fracturing prior to inducing a fire front and retorting oil shale in place. Its main advantage lies in the fact that it can create extensive fracturing while holding the cost per volume fractured to a minimum. However, there is also the possibility of venting radioactive gases into overlying groundwater formations, and this could result in the radioactive contamination of groundwater. Preventative solutions to the problem include: (1) precise reconnaissance of groundwater resources within the area to be affected, and (2) the application of previous information and test results regarding nuclear detonations in similar rock types (Pfeffer, 1974).

Airborne emissions

Most of the oil shale industrial operations, which include drilling, blasting, crushing, conveying, retorting, and upgrading, produce and emit dust, hydrocarbons, and sulfur and nitrogen compounds. Unless precautionary measures are employed, they will directly contribute to air pollution. Since the geographic area is subject to temperature inversions, concentration of air pollutants could occur and be in excess of state air quality standards. The oil shale industry could apply the mining and oil refining industries' methods to control these emissions. This involves precipitators and enclosed systems for containing dust, smokeless flares for venting volatile hydrocarbons, and recovery of elemental sulfur. The elimination of airborne emissions can be accomplished by closely monitoring the industry, implementing applicable techniques, and enforcing air pollution legislation (Pfeffer, 1974).

Carbon dioxide problem

Shale oil, like other synthetic fuels, requires more energy for its production than does crude oil. Preliminary calculations suggest that retorting of oil shales from the Green River Formation and burning of the product oil could release one and one-half to five times more carbon dioxide than the burning of conventional oil to obtain the same amount of usuable energy.[18] Most of the extra energy is heat which can be used to convert the solid kerogen into liquids and gases. The oil and gas are extracted by heating the rock to temperatures of about 500° to 1000° C. This heat is supplied by burning some of the retorted oil or gas, or by burning organic matter left in the shale after oil and gas are extracted. Much, if not all, of the remaining organic matter may be burned in the retort.

The amount of CO_2 produced by extracting and burning oil shale depends upon the retorting technique and variations in mineralogy and organic content of the shale. Low-temperature indirect retorting processes operate at temperatures near 500° F, and derive their heat from an external source. The carbonate minerals in the oil shale are not calcined significantly at this temperature to release much carbon dioxide. However, high-temperature retorting processes, utilizing heat generated directly from the combustion of organic carbon in the oil shale, commonly result in temperatures of 700° to 1000° C. At these temperatures, the carbonate minerals are calcined, and some are even completely decomposed. This liberates significant amounts of carbon dioxide. More CO_2 is added to the air by the combustion of organic carbon (Sundquist and Miller, 1980). Thus, the rate of carbon dioxide release from oil shales will ultimately depend on the retorting technique and the rate of exploitation which could last for more than a century depending upon our energy needs.

CONCLUSION

One may conclude, since the oil shale in the Green River Formation is distributed widely and abundantly, it is a logical substitute for the diminishing supply of petroleum. However, oil shale development is not without environmental hazards. Before it can compete in the marketplace, the destructive environmental unknowns must be solved economically. Thus, each of the available technologies must be scaled up to provide reliable economic data and operability, and assesed as to the environmental impact upon the area in question. Once these factors have been solved, then the shale oil may be produced for consumption.

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